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A COMPARISON OF INHALATION, SPONTANEOUS AND RAPID EXTERNAL REWARMING OF MILDLY HYPOTHERMIC SUBJECTS

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ABSTRACT

Eight healthy males were each cooled on four occasions and then rewarmed by one of three rewarming procedures: by inhalation of warmed and humidifed air once at 40°C and once at 45°C, by immersion in 40°C water and by spontaneous shivering. Using rectal temperature as the measure of core temperature, the results showed that rapid external rewarming in 40°C water produced the quickest rates of rewarming along with the smallest magnitude and duration of afterdrop. There were no significant differences in rewarming rate or afterdrop between inhalation rewarming and spontaneously rewarming (shivering). Inhalation rewarming led to a depressed metabolic rate as compared to spontaneous rewarming which was not compensated for by the heat provided through the respiratory tract. It is concluded that for mildly cooled subjects, the most efficient procedure of rewarming is by rapid external rewarming in 40°C water.

INTRODUCTION

Numerous techniques are available to rewarm hypothermic victims. Using passive means, the victim is insulated from further heat loss and he produces heat metabolically by shivering. Using active rewarming, the body temperature is raised by an external heat source. Rewarming efficacy is measured by the changes produced in core temperature following initiation of a procedure. Efficient techniques result in a rapid but controlled raising of the core temperature and minimal afterdrop. The afterdrop is the continued fall of core temperature during the initial minutes of rewarming. The rate of rewarming depends upon several factors including the technique selected, the insulation provided, the environment in which the rewarming is conducted and the degree of hypothermia in the subject.

Inhalation rewarming has been suggested as a practical field technique for rewarming (1). This is based on the postulation that the lungs would be an ideal heat exchanger for rewarming hypothermia victims because of their large surface area and contact with blood flow (1). However, studies describing the efficacy of this method have been inconclusive. Using a portable resuscitation unit which mixed CO_2 and soda lime and produced sufficient heat to warm and humidify an oxygen gas mixture, Lloyd (1,2) reported that subjects' body heat could be increased and respiratory heat loss prevented. Studies by Hayward and Steinman (3) and Collis et al. (4) showed that inhalation rewarming raised body temperature 1.5 to 2.0°C per hour. The magnitude and duration of the afterdrop following cold water immersion were also reduced.

These findings have been disputed in recent studies by Marcus (5) and Guild (6). In both studies, the rates of rewarming and the duration and magnitude of the afterdrops following inhalation rewarming were no different from those recorded during spontaneous rewarming by shivering.

The present laboratory investigation was conducted to resolve the discrepancy in claims of the beneficial effects of inhalation rewarming. Inhalation rewarming is compared to rapid external rewarming and to spontaneous rewarming by shivering.

METHODS

Eight healthy males (aged 21-32) volunteered to participate in four cold water immersions and subsequent rewarmings. Height, weight, and percent body fat were determined for each subject and are presented in Table 1. Percent body fat was calculated from body density determination by hydrostatic weighing (7).

BODY TEMPERATURE MEASUREMENTS

Rectal temperature (Tre) was used to indicate core temperature the anal sphincter. Temperatures were recorded every minute using an automated data acquisition system (HP85 computer, 3947A Scanner/Voltmeter).

Metabolic rates were determined by an automated gas analyzer system (Ergo-Oxyscreen, Jaeger Inc.) for 10 minutes prior to cooling, for 5 minutes each on four occasions during the cooling period and three times during the rewarming periods.

REWARMING TECHNIQUES

Three rewarming protocols were administered to the subjects:

a. **Spontaneous Rewarming**

Spontaneous rewarming served as the control method for the experiment. Following immersion, subjects were laid down on a cot, covered by two wool blankets, and allowed to rewarm spontaneously by shivering. They were monitored for 60 minutes, then completed the rewarming in a 40°C hot water tub;

b. **Inhalation Rewarming**

Following immersion, the identical protocol to the spontaneous rewarming was followed with the addition of being fitted with the inhalation rewarming equipment. The equipment used was the commercially available "Heat-Treat" inhalation rewarming device (Alert Manufacturing Inc., Vancouver, B.C.). It consists of a plastic oro-nasal mask attached by straps placed around the back of the head, a simple mixing device which controlled and delivered steam mixed with variable proportions of room air and a steam source which consisted of a plexiglas box containing a thermostatically controlled electrical heating element. The air temperature was controlled to deliver heated humidified air at either 40°C or 45°C. A low-dead space one-way valve allowed the subject to inspire the air on a demand basis. Thermistors were placed before and after the inspiratory and expiratory valves to monitor the gas temperatures. The expiratory port of the valve was directly connected to the automated gas analyzers for determining metabolic rates. Following 60 minutes of inhalation rewarming, the subjects entered the hot tub to complete their rewarming; and

c. **Rapid External Rewarming**

Following immersion subjects entered a hot tub of water controlled at 40°C. The subjects were seated on a wooden bench in the tub but assumed a semi-reclined position in order to be immersed up to the neck. The water temperature was maintained by an electric heater and stirred by an electric pump and two aerating jets at the sides of the tub.

PROTOCOL

All experiments were carried out in a laboratory which was controlled at 21°C and 50% humidity. On arrival, the subjects changed into swim trunks and were fitted with the temperature thermistors. They then laid down on a cot, were covered with a blanket, and allowed to rest for 30 minutes. Recording of Tre began during the rest period and continued until the completion of the rewarming phase. Metabolic rate was determined during the final 10 minutes of the resting period.

Following the rest period, subjects were cooled in a whole body water calorimeter (8) controlled at 22°C. They were immersed for 60 minutes, or less if the rectal temperature had fallen 1°C from the pre-immersion value. Heat loss for each subject was determined by direct calorimetry as previously described (8).

Following cooling, the subjects were removed from the calorimeter and moved to the appropriate rewarming site. The order of presentation of the rewarming techniques was randomized for all subjects. The time from leaving the calorimeter to initiation of a rewarming protocol did not exceed 3 minutes. After the rewarming, subjects were asked for their impression of the rewarming protocol.

The time course changes for Tre during rewarming were analyzed to determine three parameters: the magnitude of the afterdrop, the duration of the afterdrop and the average rate of rewarming (see Figure 1). The afterdrop is described as the magnitude of the decline in Tre after the subject is removed from the cold water and as the duration of time for it to reach its minimum temperature. The rewarming rate describes the rate of increase in Tre from its minimum value. The mean values for each parameter were compared between different rewarming protocols by using Student's t-test for independent means. Results were considered significant for p values less than 0.05.

RESULTS

1. **Cooling Phase**

Table 2 summarizes the average heat loss, mean decrease in core temperature and rate of decrease for the final 20 minutes of immersion of Tre prior to administration of each rewarming protocol. There were no significant differences among the groups for any parameter prior to the rewarming. The rate of cooling was inversely correlated with percent body fat, with the thinnest subjects generally cooling the quickest.

2. **Rewarming Phase**

Table 3 compares the three parameters for each of the rewarming techniques. Rapid external rewarming in hot water produced

significantly greater rewarming rates ($p<0.01$) as compared to the other protocols followed. There were no significant differences between rewarming spontaneously and inhalation rewarming with either 40° or 45°C air. Similarily the magnitude and the duration of the afterdrop was significantly less ($p<0.01$) with rapid external rewarming when compared to the other rewarming procedures.

Figure 2 compares the metabolic rates prior and during the cooling period with those during the rewarming procedure. As expected there was a significant rise in metabolism during the cooling period. However, during the rewarming period, metabolism varied among the different techniques. During both spontaneous and rapid rewarming, the metabolic rates were significantly higher than with inhalation rewarming. In fact, metabolic rates during inhalation rewarming were not significantly different from resting metabolism prior to the cooling.

Respiratory heat loss and heat gained by the respiratory tract were calculated using oxygen consumption and ventilatory data (9). Table 4 summarizes the net heat gained or lost after calculation of both the respiratory and metabolic contribution. Rewarming spontaneously contributed a greater amount of heat back to the body than the calculated total of respiratory and metabolic heat during inhalation rewarming.

SUBJECTIVE EVALUATION OF TECHNIQUES

a. **Spontaneous Rewarming**

Although it was simple to prepare the subject for rewarming with the blankets, they remained uncomfortable for the duration of the rewarming period. Both the periods of shivering and the constant sensation of feeling cool or cold made the period of rewarming unpleasant;

b. **Inhalation Rewarming**

There were a number of procedural problems encountered during the inhalation rewarming. If users are unfamiliar with the apparatus, the delivery of the heated and humidified air may be affected. Initially, it was difficult to get a tight-fitting seal with the oro-nasal mask with either the the straps provided or with a modified set which was sewn for the experiment. The seal would either loosen as the subject lay down or was difficult to achieve when the attaching was attempted with the subject lying down.

Without practise, the simple mixing device for combining the steam and room air was found to be difficult to manipulate and control it would probably be even more difficult under field conditions, especially if it is cold. Our experiences in this study showed that 45°C is the upper range of tolerable inspired temperature. Temperatures above 45°C were quickly felt by the subjects as causing a burning feeling on the lips. Minor inconveniences encountered included condensed water collecting in the hosing and valve system.

Although the amount of shivering was decreased during the inhalation rewarming, the subjects still felt cool and a number found breathing the warm humidified air uncomfortable; and

c. **Hot Tub Rewarming**

Entering the hot tub following the cooling phase was found not to be difficult although there were individual differences in the rate at which the subjects would enter the water. Similarly there were no problems tolerating the water during the rewarming. It was much more uncomfortable entering the 40°C water following 60 minutes of one of the other rewarming techniques.

DISCUSSION

Rapid external rewarming, such as immersion in hot water has often been recommended as the method of choice for rewarming hypothermic victims (10). Advocates of direct core rewarming by inhalation however, suggest that rapid rewarming is not significantly faster than inhalation rewarming and may result in greater afterdrops and circulatory collapse (3,4). The theoretical basis for direct core rewarming is that it delivers heat specifically to the central circulation and vital organs avoiding problems associated with peripheral dilatation. While direct methods of core rewarming such as extracorporeal circulation and peritoneal dialysis have been shown to be effective, they are restricted to hospital settings. To date however, there are conflicting data to the efficacy of the inhalation rewarming technique (11).

Our study showed that rewarming rates were significantly greater by rapid rewarming than with inhalation rewarming. In fact, the rates of inhalation rewarming were not significantly greater than rewarming spontaneously. Neither the magnitude nor the duration of the afterdrop were significantly different between inhalation and spontaneous rewarming. The magnitude of the afterdrop was significantly less for rapid external rewarming compared to the other techniques. From our study, there is little doubt that for mildly cooled subjects, rapid external rewarming achieved by sitting in a hot tub at 40°C was the most

efficient technique of rewarming producing the smallest afterdrop in both duration and magnitude.

It has been argued the afterdrop observed in core temperature following the initiation of rewarming, and most notably during rapid external rewarming, is a result of the return of cold blood from the periphery. It is thought that the afterdrop could potentiate the occur- physiological significance to the occurence of an afterdrop. Hayward et al. (14) have recently acknowledged this view of afterdrop but suggest it is only applicable to rectal measurements. They have shown a decline in cardiac temperature during rapid rewarming and describe this as a circulation-induced afterdrop. However, since this study was performed on only one subject, their findings require further confirmation.

The peripheral vasodilation which occurs during rewarming in a hot tub has also been associated with hypovolemic shock following the commencement of rewarming. The diminished central blood volume resulting from fluid shifts towards the periphery with the dilation places further stress upon the cardiovascular system in trying to maintain arterial pressure with the most detrimental effects upon the coronary circulation. Although those who support the use of inhalation rewarming specifically describe hypovolemic shock as a problem associated with rapid rewarming, it can be encountered in any individual, regardless of which rewarming technique is used (15). Marcus (5), who supports the idea that hypovolemic shock can occur with any rewarming procedure, suggests that this phenomenon is better described as rewarming collapse.

Although inhalation rewarming cannot be considered an aggresive rewarming technique, it does prevent respiratory heat loss and provides some additional heat to the body, as previously suggested by Lloyd et al. (2) and confirmed by the data from this study. This attribute probably has its greatest benefit for treatment in a hyperbaric environment where respiratory heat loss is often the greatest source of heat loss from the body (16). Although the prevention of respiratory heat loss in itself may be helpful, Morrison et al. (17) also showed metabolism is depressed during inhalation rewarming. This was confirmed in the present study where it is further shown that the depressed metabolic heat production is not compensated for by the increased respiratory heat gain.

The rapid rewarming in our study was carried out in 40°C water. Although water temperatures as high as 43°C have been used previously (3,4,5), our preliminary studies indicated that although higher temperatures were less tolerable during entry, they were more effective for rewarming. Our results are also different from those of Popplow and Kuehn (18), who state that rewarming in hot tub should not be attempted in water above 38°C because it can cause some discomfort and could produce syncope. Recent unpublished data of rewarming in a hot tub from this laboratory indicated that while initial entry into a 37 to 38°C hot

tub was more comfortable than entering one at 40°C, the subjects felt cool after a few minutes and that rewarming was significantly slower.

It is also not surprising that 20 min in a 40°C hot tub waiting for the rectal temperature to rise to pre-immersion levels as described by Popplow and Kuehn (18) would produce overheating and discomfort. During the present study, the responses of various core sites to different rewarming procedures was also measured (19). The results indicated esophageal temperature rose 2 to 3 times quicker than rectal during rewarming in the hot tub (19). As a consequence, not detecting the rapidly rising core temperature by using the slower responding rectal temperature would have led to the observed symptoms of Popplow and Kuehn.

CONCLUSIONS

1. In mildly cooled subjects, the fastest rate of rewarming with the shortest and smallest afterdrop was obtained by rapid external rewarming in a 40°C water bath. This method was significantly more efficient than the other procedures, spontaneous rewarming, and inhalation rewarming at either 40°C or 45°C.

2. The rates of rewarming were not significantly different between spontaneous rewarming (ie. shivering) and inhalation rewarming with either 40 or 45°C air.

3. Inhalation rewarming was accompanied by a depressed metabolic rate as compared to spontaneous rewarming. Despite the prevention of respiratory heat loss and the heat gained through inhalation rewarming was insufficient to compensate for the depressed metabolism when net heat gain was calculated.

RECOMMENDATIONS

1. For mildly hypothermic victims, rapid external rewarming is the method of choice.

2. Inhalation rewarming via equipment such as the "Heat-Treat" device does not provide sufficient benefit to warrant its inclusion as basic rescue equipment for CF operations. Inhalation rewarming may have greater benefit during treatment in hyperbaric environments where respiratory heat loss is often of greatest concern.

3. Rewarming of victims who are moderately hypothermic, that is a core temperature less than 35°C, should be carried out under proper medical supervision in an appropriate facility. If this is not possible, a conservative approach in treating the victim should be followed.

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TABLE 1

Physical Characteristics of the Subjects (N=8)

	Height (cm)	Weight (kg)	Body Fat (%)
Mean ±S.D.	179.9±7.5	76.8±5.5	13.8±6.4
Range	(167-190)	(68.5-85.0)	(5.0-21.5)

TABLE 2

Cooling Characteristics of the Subjects (N=8)

	Heat Loss (KJ)	ΔTre (°C)	Cooling Rate (°C/hr)
SR	1269 ±153.7	0.37 ±0.35	0.86 ±0.57
IR40	1301 ±147.5	0.29 ±0.30	0.70 ±0.51
IR45	1272 ±139.2	0.36 ±0.32	0.77 ±0.77
RER	1266 ±134.8	0.28 ±0.30	0.89 ±0.62

SR - Spontaneous Rewarming; IR40 - Inhalation Rewarming with 40 °C;
IR45 - Inhalation Rewarming with 45 °C; RER - Rapid External Rewarming

TABLE 3

Comparison of the Afterdrop Characteristics and Rewarming Rates

	SR	IR40	IR45	RER
Rewarming Rate (°C/hr)	0.82 ±0.48	0.28 ±0.38	0.76 ±0.50	2.62 ±0.92
Magnitude of Afterdrop (°C)	0.66 ±0.13	0.47 ±0.20	0.52 ±0.21	0.31 ±0.12
Duration of Afterdrop (min)	51.9 ±11.4	51.1 ±12.0	46.8 ±20.3	16.2 ±8.4

SR - Spontaneous Rewarming ; IR40 - Inhalation Rewarming with 40 °C
IR45 - Inhalation Rewarming with 45 °C ; RER - Rapid External Rewarming

TABLE 4

The Heat Balance of the Subjects During 60 Minutes of Metabolic (SR) or Inhalation Rewarming (IR).

Rewarm Method	Respiratory Heat Exchange (kJ/hr)	Metabolic Heat Production (kJ/hr)	Net Heat Gain (kJ/hr)
SR	-47.5	507.2	459.7
IR40	13.7	389.4	375.7
IR45	25.6	367.5	341.9

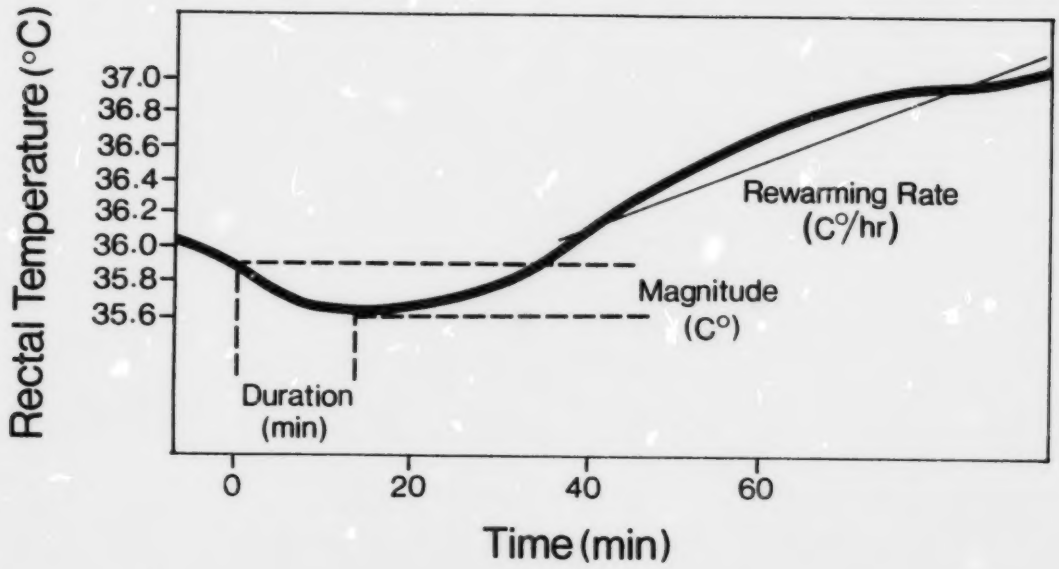

FIGURE 1

A figure depicting the three parameters measured in analyzing the afterdrop and rewarming.

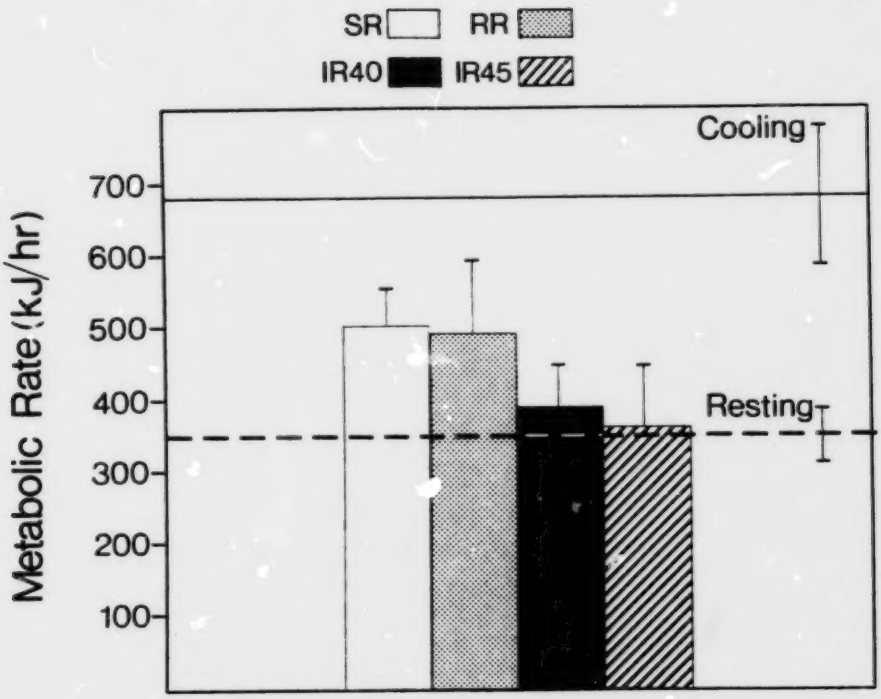

FIGURE 2

The metabolic rates measured during the different rewarming procedures and comparison to average resting and cold immersion metabolic rates.